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An Analysis Package for Bolometer Ground Testing

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Abstract. ESA's Herschel Space Observatory, to be launched in 2007, will be sensitive to far infrared wavelengths beyond 60 μm. The longer wavelength interval between 200 and 670 μm will be covered by SPIRE, a combination of broad band camera and Fourier transform spectrometer. SPIRE will use exclusively spiderweb bolometers as detectors, which are manufactured and tested at JPL. We describe a data analysis package developed at the NASA Herschel Science Center at IPAC in support of the testing activity, which expects to cover 12 detector arrays with between 24 and 144 channels each. The package consists of a widget based viewer allowing immediate display and limited processing of the 193 recorded data channels in the lab and a suite of subroutines and scripts, allowing fast and flexible pipeline data reduction.

1. Software Structure

BoloLibrary is a software package written in IDL (interactive data language) to support the analysis of test data from bolometers, as used in SPIRE, one of three instruments on board of the planned Herschel Space Observatory. The bolometer arrays undergo a series of performance tests in a laboratory cryostat at JPL (Nguyen et al. 2004). The raw data products emerging from the test facility BoDAC are files that start with a short ASCII header, followed by a binary data array. This array consists of one channel with time information and 192 signal channels. These files and some additional ASCII parameter files are the input to the programs described in this paper. The following major data analysis tasks are presently performed using *BoloLibrary*:

- Signal Viewing
- Noise Analysis
- Optimum Bias Determination
- Time Constant Determination
- Load Curve Analysis

Figure 1 shows the data flow starting from the initial binary files produced by BoDAC to the various analysis results. In an initial conversion the data is written to a file in the more widely known FITS format. This step is also used to change channel names and units if necessary, to remove amplification factors of the BoDAC electronics, and to convert the signals of temperature sensors into units of Kelvin. Two editable ASCII files and a temperature conversion routine

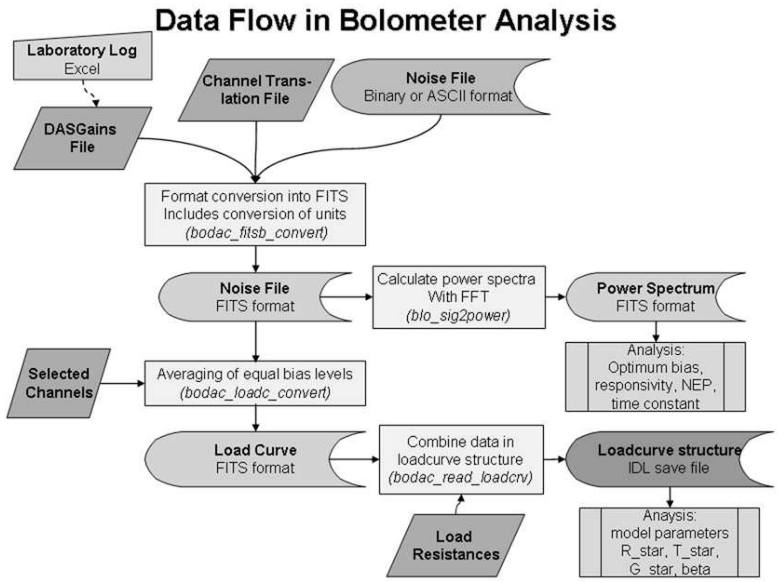

Figure 1. The general data flow from the initial BoDAC files to the analysis results.

contain the necessary information, allowing for enough flexibility in an often changing laboratory environment. In our configuration the signal channels of the resulting FITS "noise" file contain either voltages in [Volts] or temperatures in [K]. The time channel is always in [seconds] starting at the beginning of the measurement. Date and other relevant metadata are found in the FITS header.

Depending on the experiment, the noise file is either transformed into a power spectrum or translated into a load curve file. A noise file is transformed into a load curve file if the bias voltage was changed during the time interval covered by the input file. In this case the respective program averages data over intervals of constant bias voltage. The channel containing the time information is replaced by the bias voltages, and the data is stored again in another FITS file, including uncertainties estimated from the scatter of the averaged data. Since the detector arrays vary in size, only the channels listed in an ASCII file "SelectedChannel.txt" are included into the load curve file. Channel selection and averaging greatly reduce the size of a load curve file and save disk space.

Load curves taken at different temperatures need to be analyzed as a whole. Therefore data from many load curve files are collected in a pointer array of IDL data structures and stored in an IDL save file. There are several procedures provided in *BoloLibrary* for dark load curve data analysis, specifically to work with these structures.

2. Laboratory Data Viewer

An invaluable tool to view and assess the quality of newly obtained data in the lab as well as when performing offline analysis, is the data viewer called

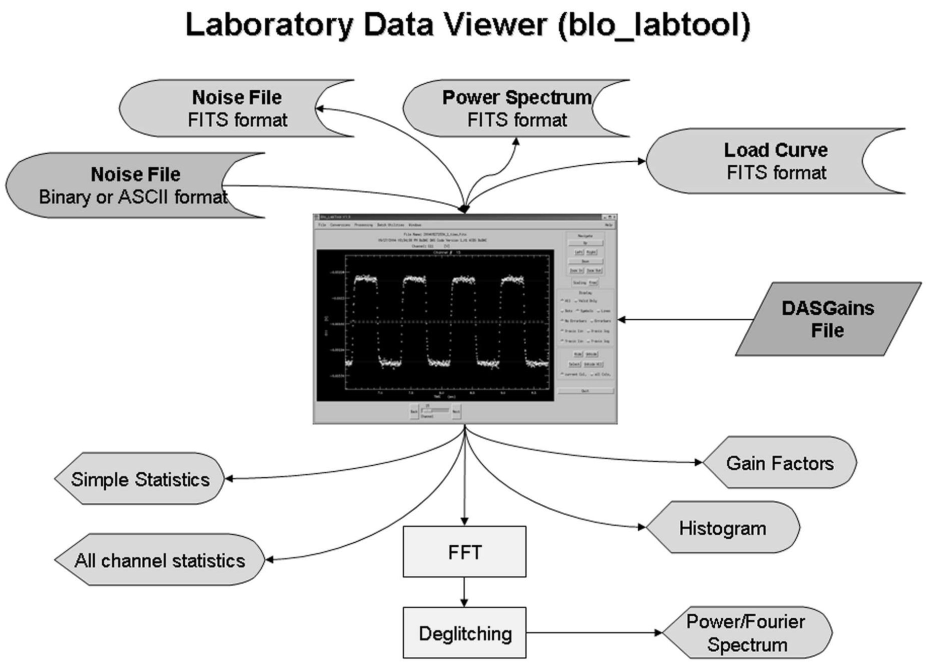

Figure 2. Input and output of the data viewer.

Blo_LabTool. Figure 2 shows the data flow chart of *Blo_LabTool*, which has an intuitive GUI and is started from the IDL commandline. It allows to rapidly view and manipulate raw data, show derived power spectra, save these and more. Data files in various formats,(.bin, .fits, .txt) can be opened from the "File"menu. Highlights of the viewer are as follows:

- Show the signal versus time plots channel by channel
- Navigate the plots and zoom in and out
- Change between symbols, dots and lines in the display
- De-select and re-select data points
- Allow multiple windows
- Calculate power spectrum of selected data range and display in new window
- Calculate and display a histogram
- Display uncertainty data if available
- Calculate and display statistics of selected data points
- Determine amplitude ratios of sine signals to measure amplification factors
- Apply conversion factors to data
- Derive load curves interactively
- Display a HTML help file in a web browser

3. Batch Analysis

Although the viewer is very important to check on certain aspects of the data, the large number of channels requires more flexibility than a GUI based tool is usually able to offer. The "production" of analysis results is controlled by IDL scripts, dedicated to individual datasets that call subroutines from a library that forms the basis of this software. Besides allowing to easily repeat processing steps, the scripts serve also as documentation for the analysis of a particular dataset. In the following we briefly touch upon each of the analysis items that are currently implemented. Several items require the data first to be transformed into power spectra.

3.1. Noise Analysis & 1/f Knee Frequency

The power spectrum derived from the output voltage of an undisturbed dark bolometer consists of a plateau in the middle, a rising power spectrum to lower frequencies that goes with 1/frequency and a high frequency roll-off. The important parameters determined by the software are the plateau level and the location of the 1/f knee, i.e. the frequency where the spectrum has reached $\sqrt{2}$ times the plateau level. A typical challenge is to automatically eliminate the microphonic lines that otherwise affect the plateau measurement.

3.2. Optimum Bias & Time Constant

These experiments involve a hot external blackbody that sends an infrared beam through a neutral filter onto the detector array. The beam is chopped with an adjustable frequency so that the detectors are illuminated alternately by the blackbody and the 300 K environmental radiation. The power spectrum of the bolometer voltage shows a line at the position of the chopper frequency. Its strength is a measure for the difference in intensity between the two infrared illumination levels. The optimum bias is determined by finding the maximum line strength while varying the bias voltage of the detector. The time constant is determined by observing the decrease in line strength when the chopper frequency is increased.

The analysis uses modules to first derive the chopper frequency for each data file in a selected clean channel, and then determine the line strength for all channels depending on either bias or chopper frequency. Simple ASCII tables are used for the IO of intermediate products. Since the coverage by different bias voltages is relatively sparse, a 2^{nd} order polynomial fit around the maximum line is used to determine the maximum with somewhat higher accuracy. By fitting $P(f) = \frac{A}{\sqrt{1+2\pi f \tau^2}}$ to the line strength depending on chopper frequency f, the thermal time constant τ of each bolometer is determined. A is the amplitude at low frequencies and a free fit parameter.

3.3. Load Curve Analysis

A dark load curve is obtained by putting the bolometer in a light-tight chamber and measuring the output voltage across the bolometer as a function of input bias voltage. Taking load curves at a variety of bath temperatures allows to determine 4 fundamental parameters R_*, T_*, G_0, and β that are required to model bolometer operation. Our models follow general theory as described by

Richards (1994), Rieke (1994), Sudiwala at al. (2002), Woodcraft et al. (2002), Nguyen et al. (2004), and others. The temperature dependence of the bolometer resistance is described as

$$R = R_* \exp \sqrt{\frac{T_*}{T}}. \tag{1}$$

After correction of voltage offsets based on the symmetry of the load curve w.r.t. the zero point, the resistances of the bolometers at zero power are determined from the slope of the load curves at zero bias. A linear fit determines the first two parameters.

The thermal conductance is modeled as

$$G(T) = G_0 (T/T_0)^\beta \tag{2}$$

so that the electric power can be expressed as

$$P = \frac{G_0}{(\beta + 1)} T_0^{-\beta} (T^{\beta+1} - T_{bath}^{\beta+1}). \tag{3}$$

Here T is the bolometer temperature, T_{bath} is the bath temperature, and $T_0 = 0.3$ K is a constant. While the load curves used to determine the zero power resistances only need to cover the smallest biases sufficient to fit a line, the parameters G_0 and β require a bias coverage that goes sufficiently beyond the turnover points, where the bolometer voltage drops due to the increasing electrical power dissipated in the bolometer and the resulting drop in resistance. The parameters are obtained by tailored nonlinear fitting routines in the library.

References

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